RHIC Run-10

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Outline

- Run-10 Overview
- Major improvements for Run-10
- Beam Physics Issues for Run-10
- Results from $\sqrt{s_{NN}}$= 200 GeV/n Au+Au
- Results from Medium Energy Runs
- Results from Low Energy Runs
- Future Plans for RHIC Ion operations
- Summary

Some Acknowledgments

- Co-Run coordinators (+LE RC): Todd Satogata, Angelika Drees, Greg Marr (11.5GeV/n RC)
- Scheduling Physicist: Guillaume Robert-Demolaize
- Management support: Wolfram Fischer, Thomas Roser, Jon Sandberg, Joe Tuozzolo
- Shift Leaders: Mei Bai, Joanne Beebe-Wang, Yue Hao, Yun Luo, Waldo MacKay, Greg Marr, Christoph Montag, Vadim Ptitsyn, Vincent Schoefer, Gang Wang
- RF Crew: John Butler, Tom Hayes, Peggy Harvey, Freddy Severino, Kevin Smith, Alex Zaltsman
- Instrumentation: Roger Connolly, Tony Curcio, Dave Gassner, Rob Hulsart, Al Marusic, Kevin Mernick, Michiko Minty, Rob Michnoff, Michelle Wilinski
- Stochastic Cooling: Mike Brennan, Mike Blaskiewicz
- An amazing operations crew!
- Maintenance and shutdown management crew led by Paul Sampson.
- Controls: John Morris, Larry Hoff, Ted D'Ottavio, Jon Laster, Charlie Theisen, Jon Reich

The entire C-AD, a collection of true professionals.

Run-10 Overview

Oct. 5,	N_2 scrubbing
Nov. 2,	45 K wave begins.
Nov. 12,	AGS Testing.
Nov. 16,	beam setup in Booster and AGS
Nov. 16-20,	RHIC Dry Run
Dec. 1,	Begin cooldown to 4.5K
Dec. 4-5,	beam setup in RHIC begins.
Dec. 22,	Original Projected Physics start
Dec. 31,	23:54, actual start of physics for 200 GeV/n
Mar. 18,	8am: End of 200 GeV/n Run, setup for 62.4 GeV/n
Apr. 9,	8am: End of 62.4 GeV/n Run, setup for 39 GeV/n
Apr. 22,	8am: End of 39 GeV/n Run, setup for 7.7 GeV/n
May 17,	5 GeV/n test run
May 27,	End of 7.7 GeV/n, setup for 11.5 GeV/n
June 7,	End of 11.5 GeV/n.
June 8,	5 GeV/n test run

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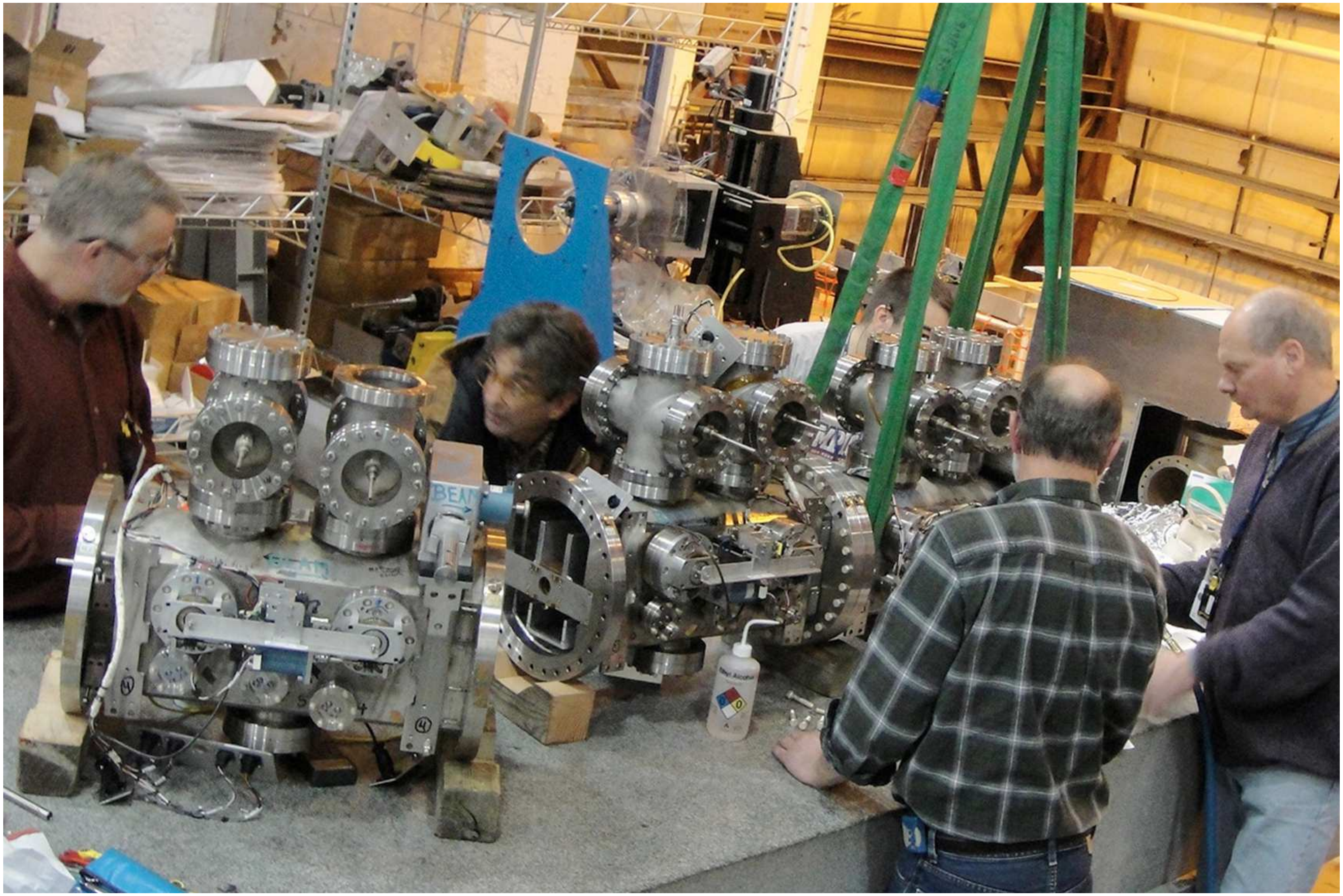
Major Improvements for Run-10

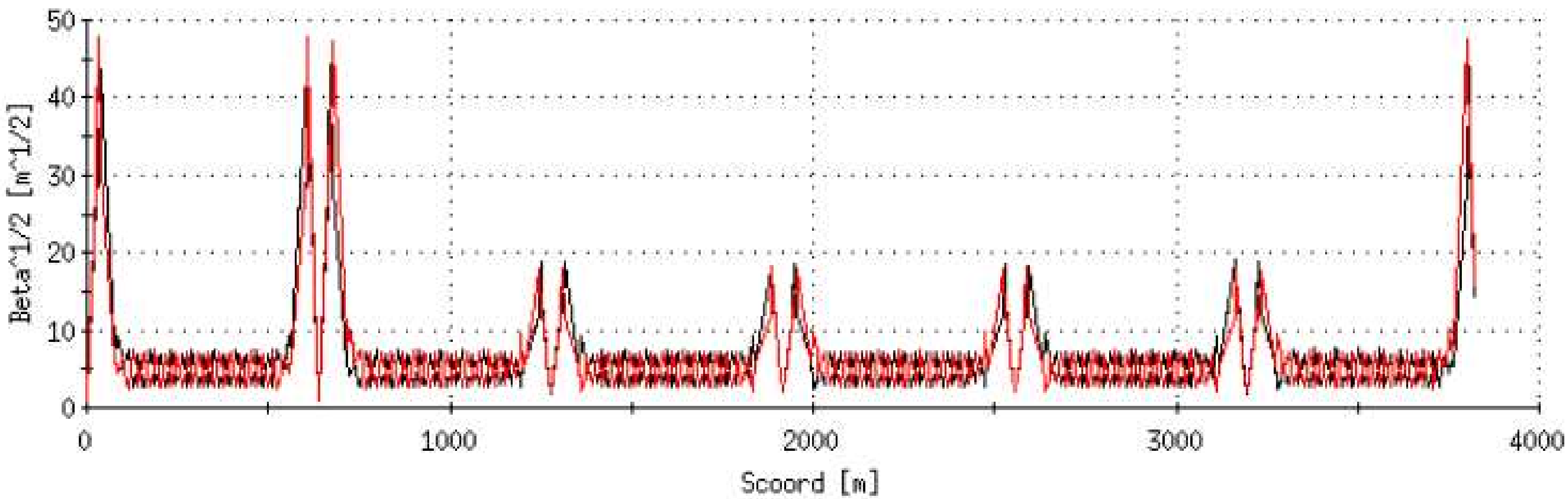
- Stochastic Cooling:
  - 2 Longitudinal systems (one per Ring)
  - 2 transverse systems (one per Ring)
- Feedback systems
  - Tune/coupling feedback improved
  - Commissioned slow orbit feedback
  - Commissioned Chromaticity feedback
  - 10 Hz orbit feedback = began commissioning
- New LLRF systems
- New Lattices with separated transition jumps
  - both rings had IBS suppression lattices

Stochastic cooling crew!



Lattice Parameters

	energy[GeV]	working point (Qx,Qy)	β*(IP 6 8 10 12 2 4) [m]
injection	9.796	B: (31.23, 32.216), Y:(31.232, 32.217)	10 10 10 10 10 10
ramp	9.796 -- 100	same	beta squeeze
store	100	B: (31.237, 32.229), Y:(31.210, 32.205)	0.75 0.75 4 4 4 4 (note: 2 mrad crossing at 4m β*)



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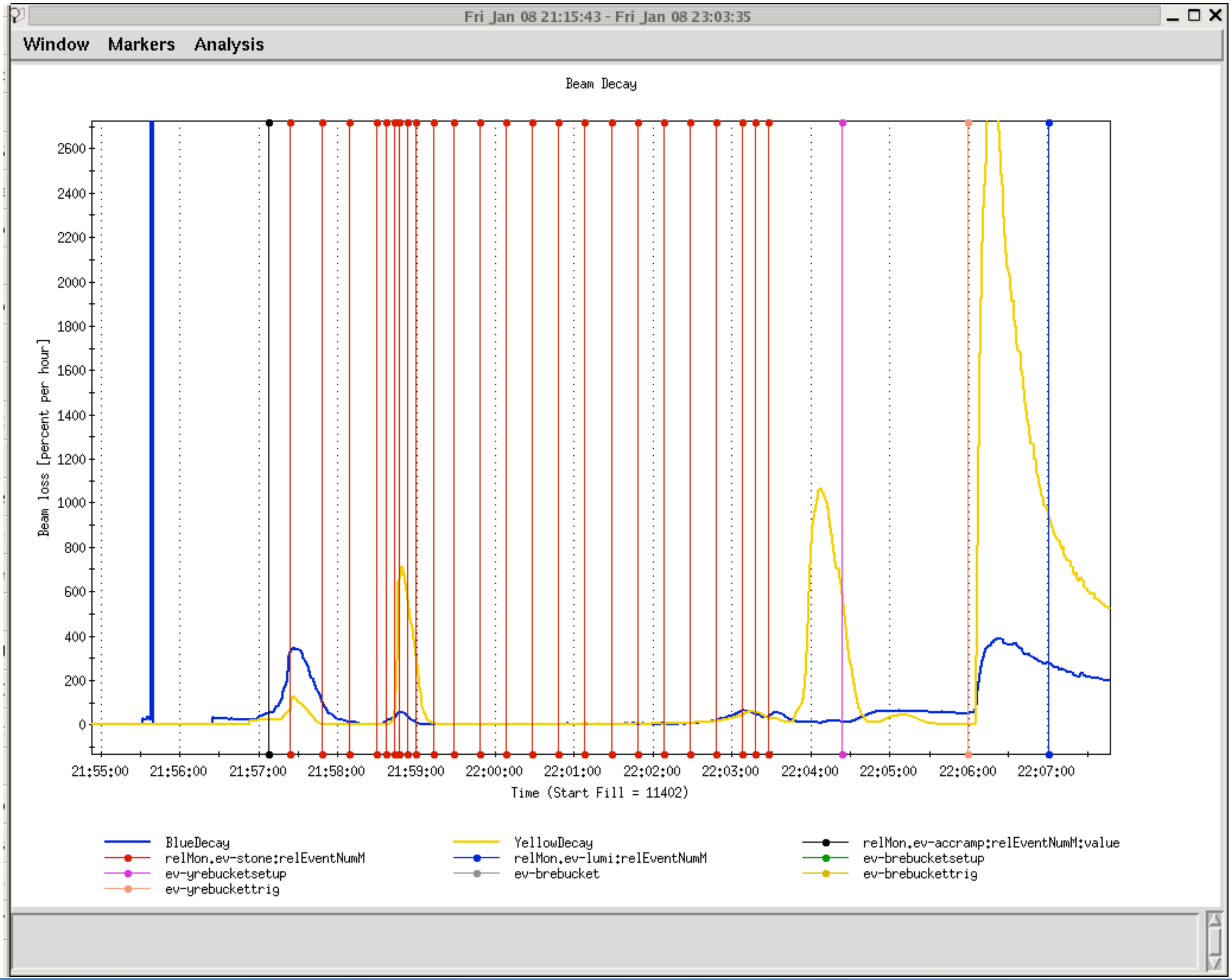
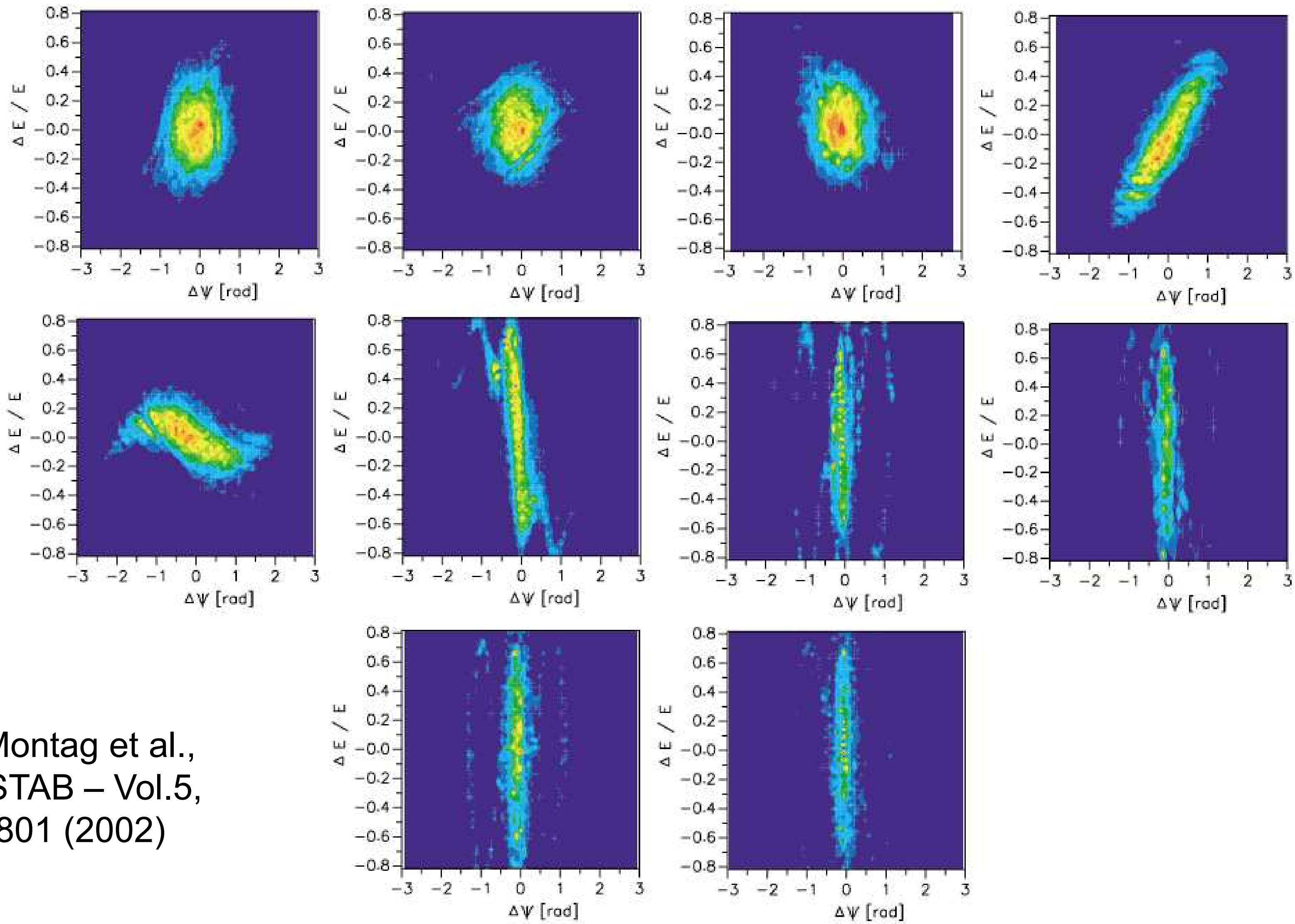
Run-10 Beam Physics Issues

- Intra-beam scattering – emittance growth due to Coulomb interactions
  - Stochastic cooling
  - IBS Suppression lattice
- Transition crossing
  - Radial stability – separate jump times, feedback
  - Instabilities & electron clouds
- Momentum aperture at rebucketing
  - Momentum spread ~ doubles
  - Small β^* = more non-linear fields sampled

Momentum Aperture



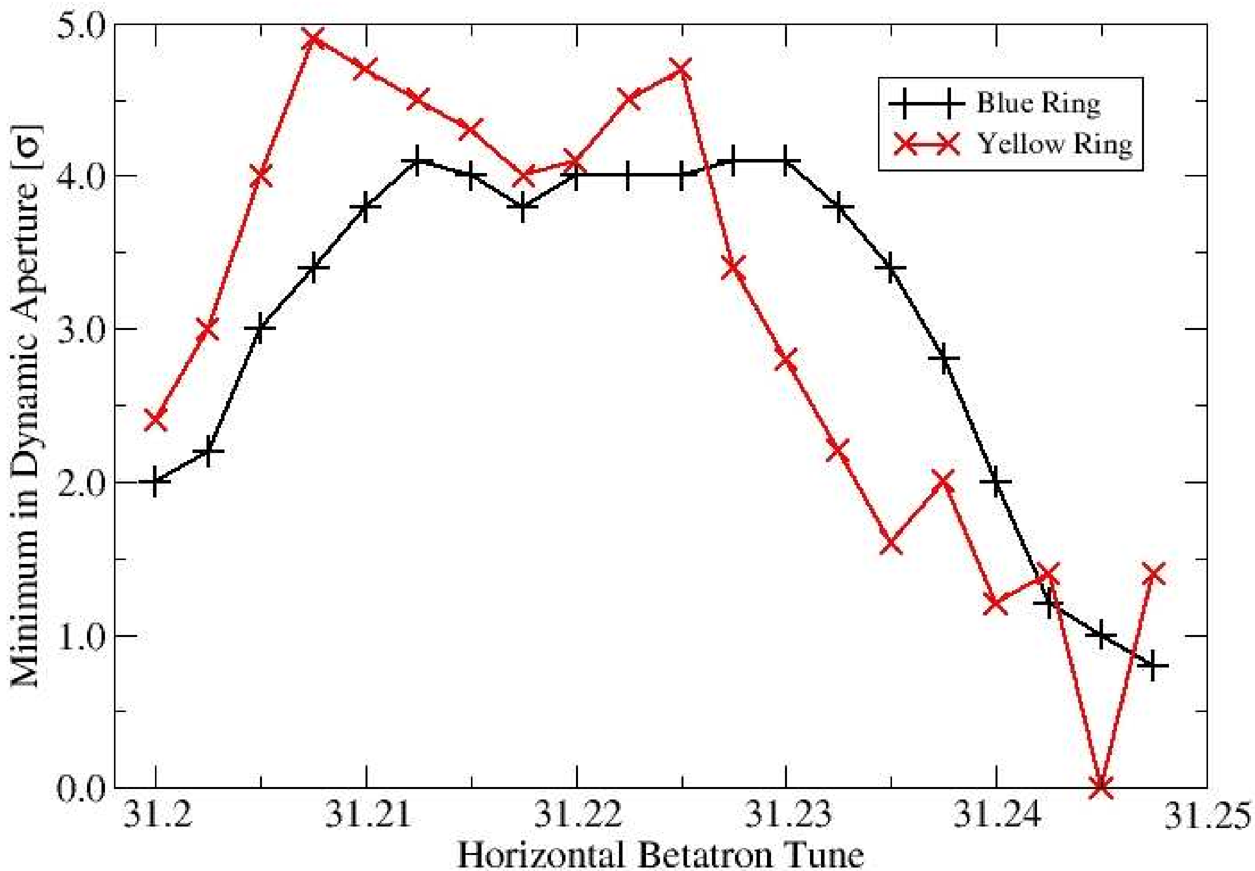
Rebucketing in RHIC



C. Montag et al., PRSTAB – Vol.5, 082801 (2002)

Momentum Aperture

Simulation from Y. Luo



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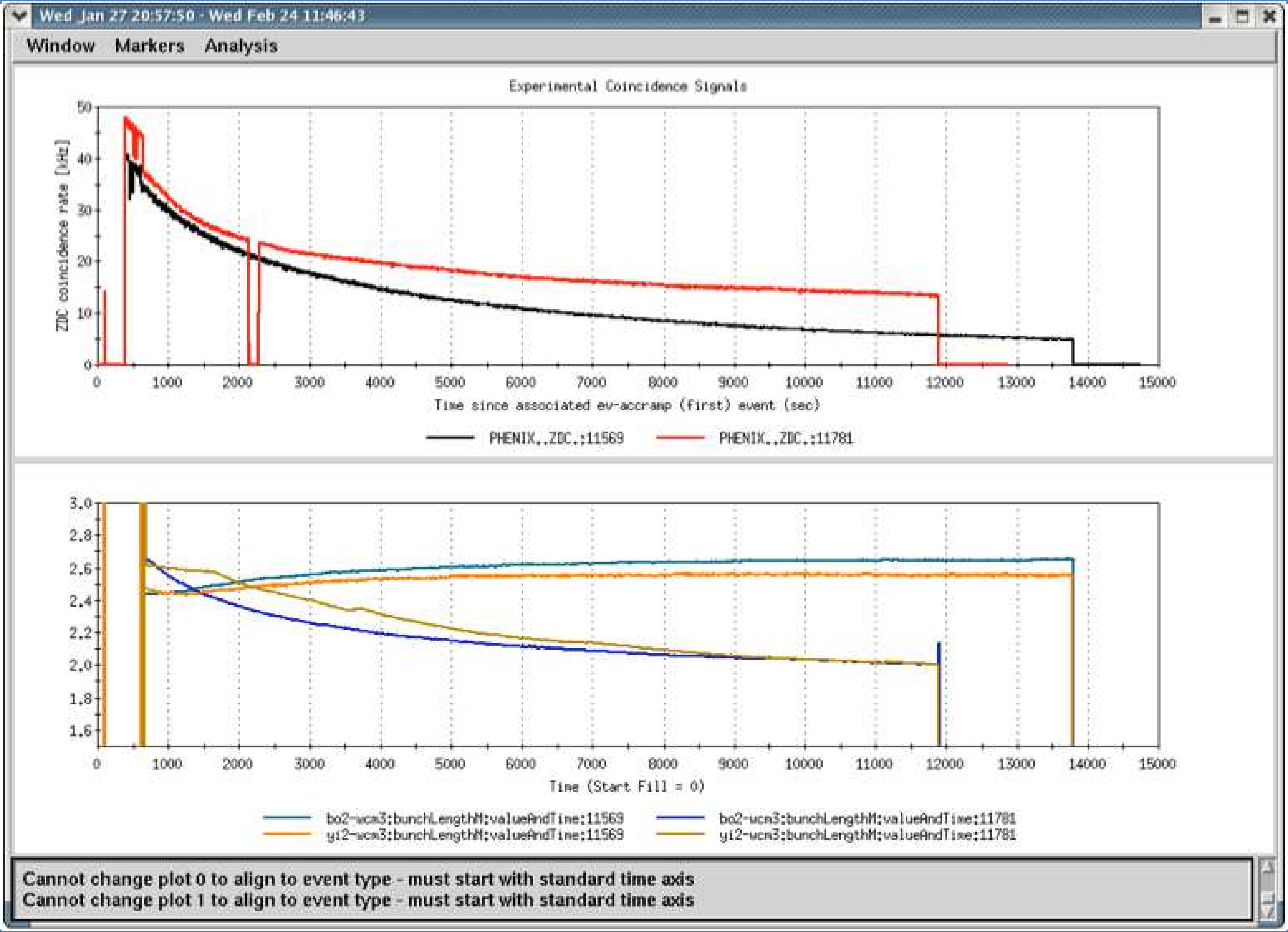
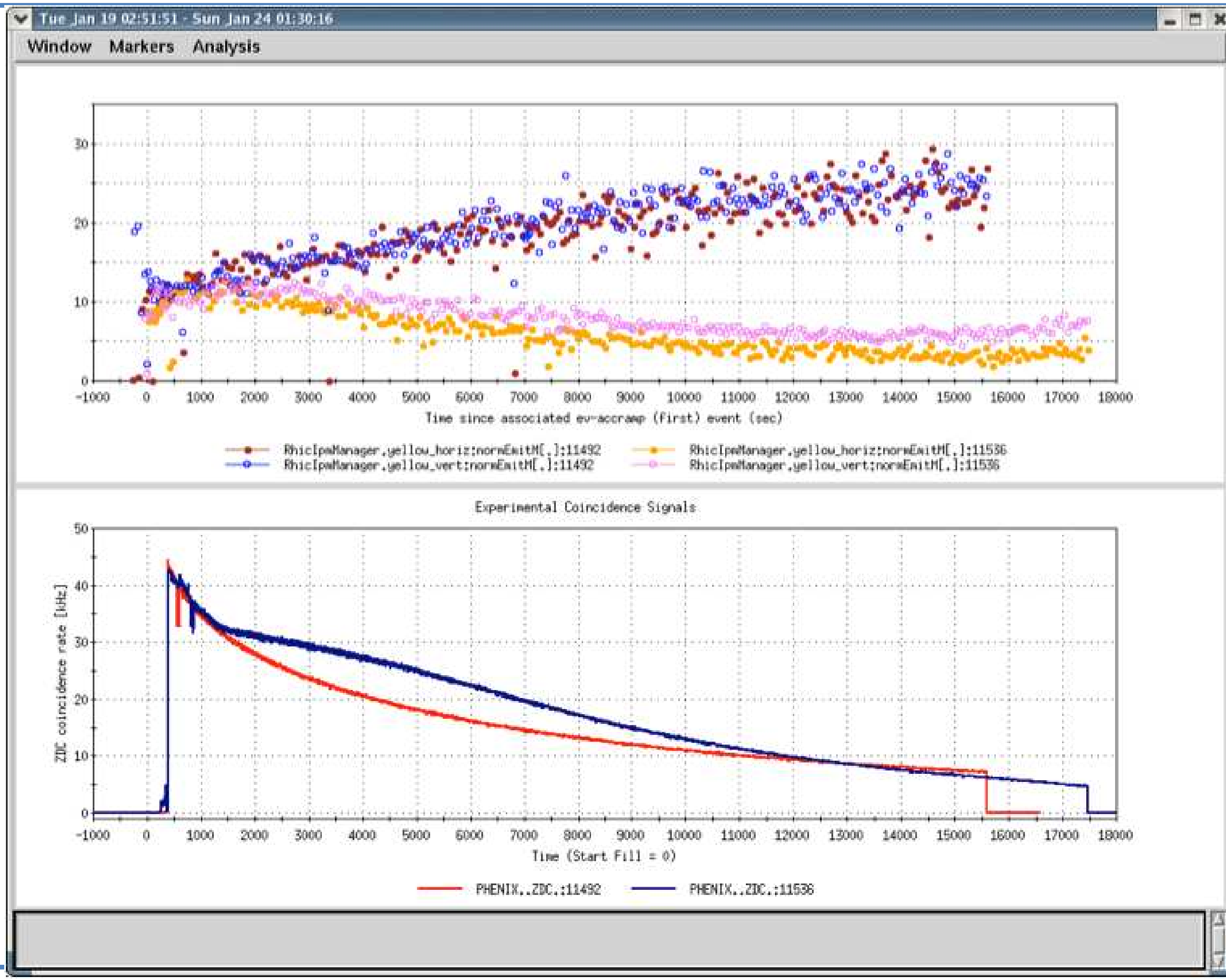
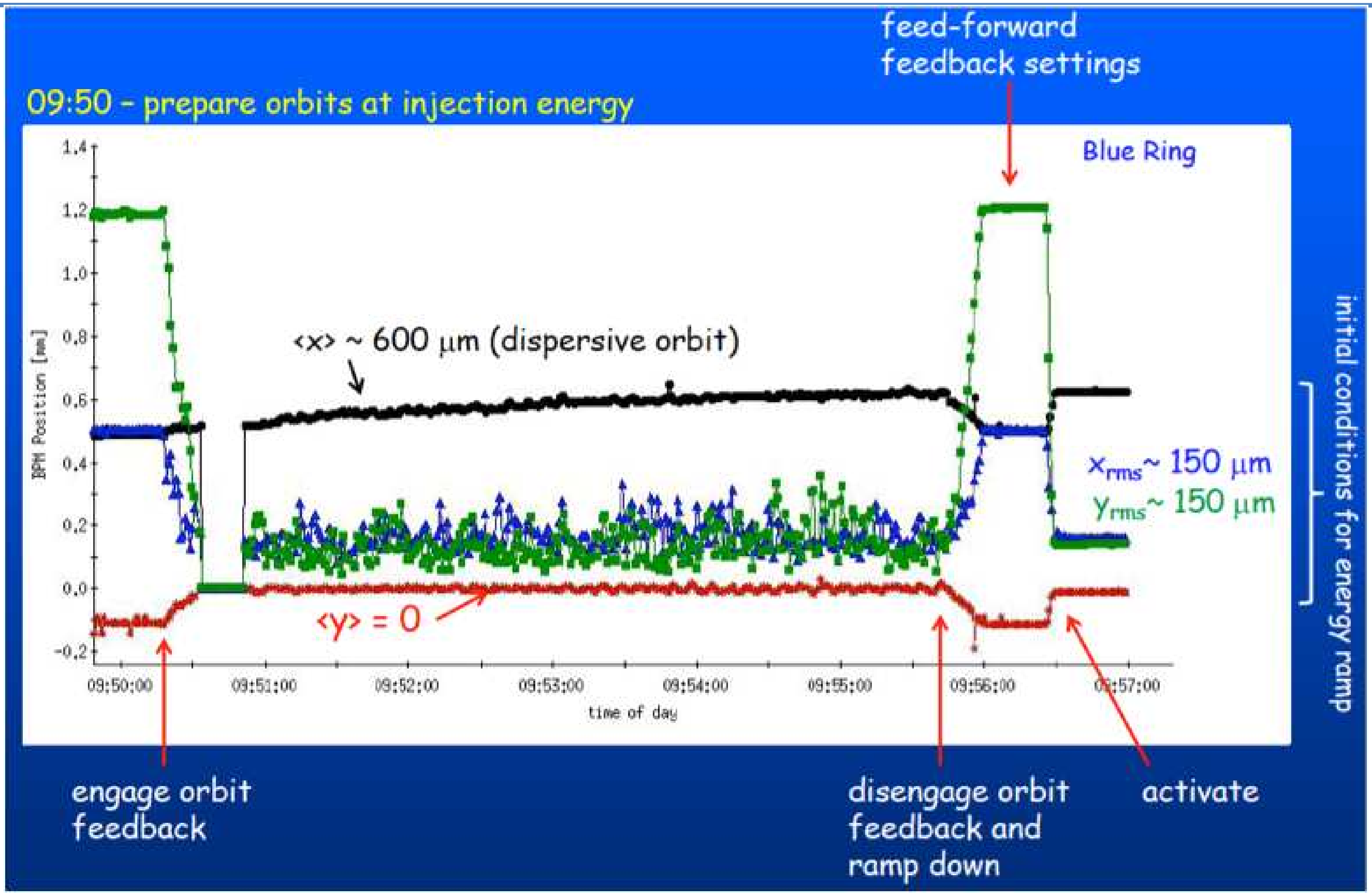
Longitudinal Stochastic cooling



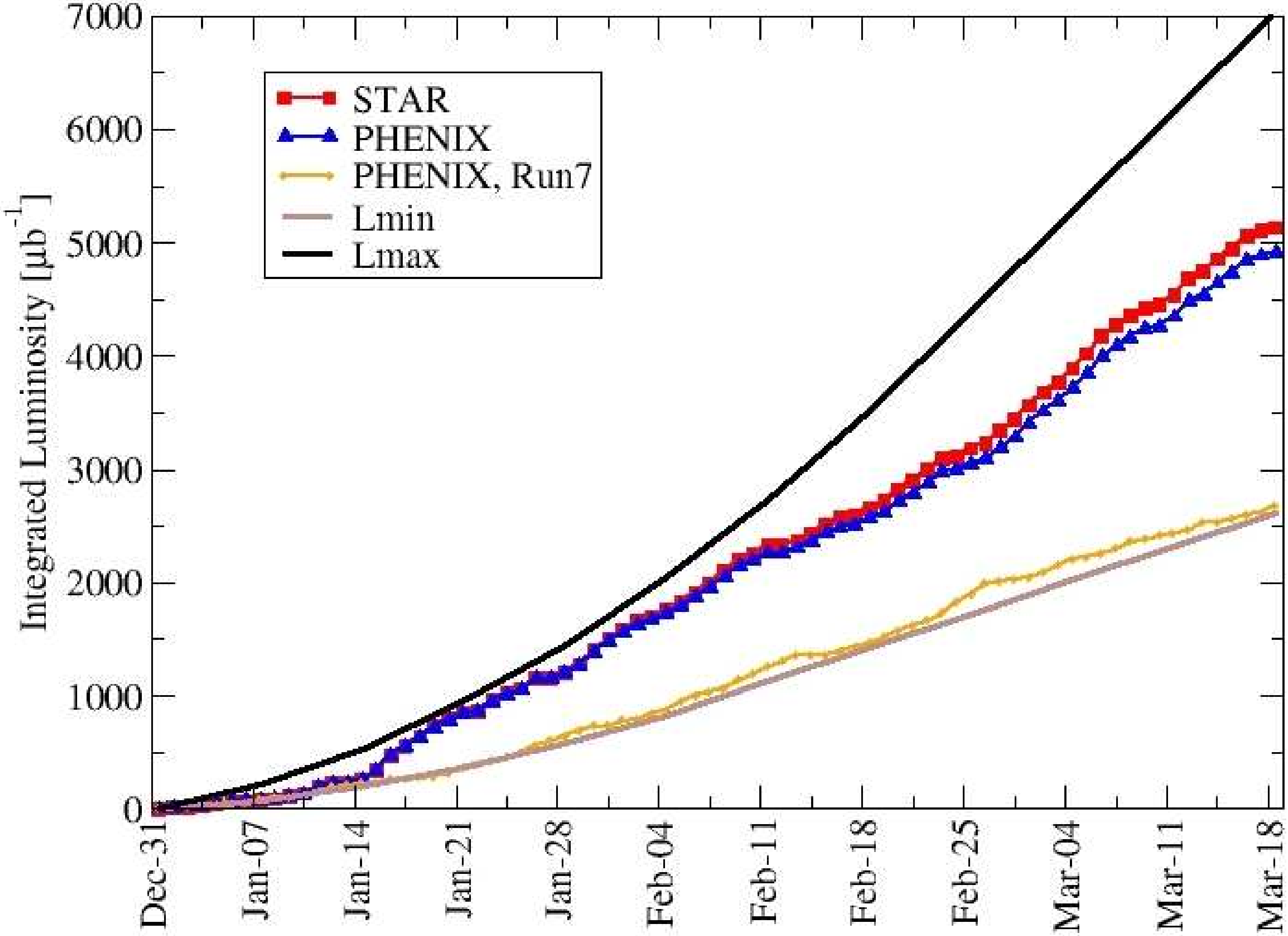
Transverse Stochastic cooling



Slow Orbit Feedback



Integrated Luminosity

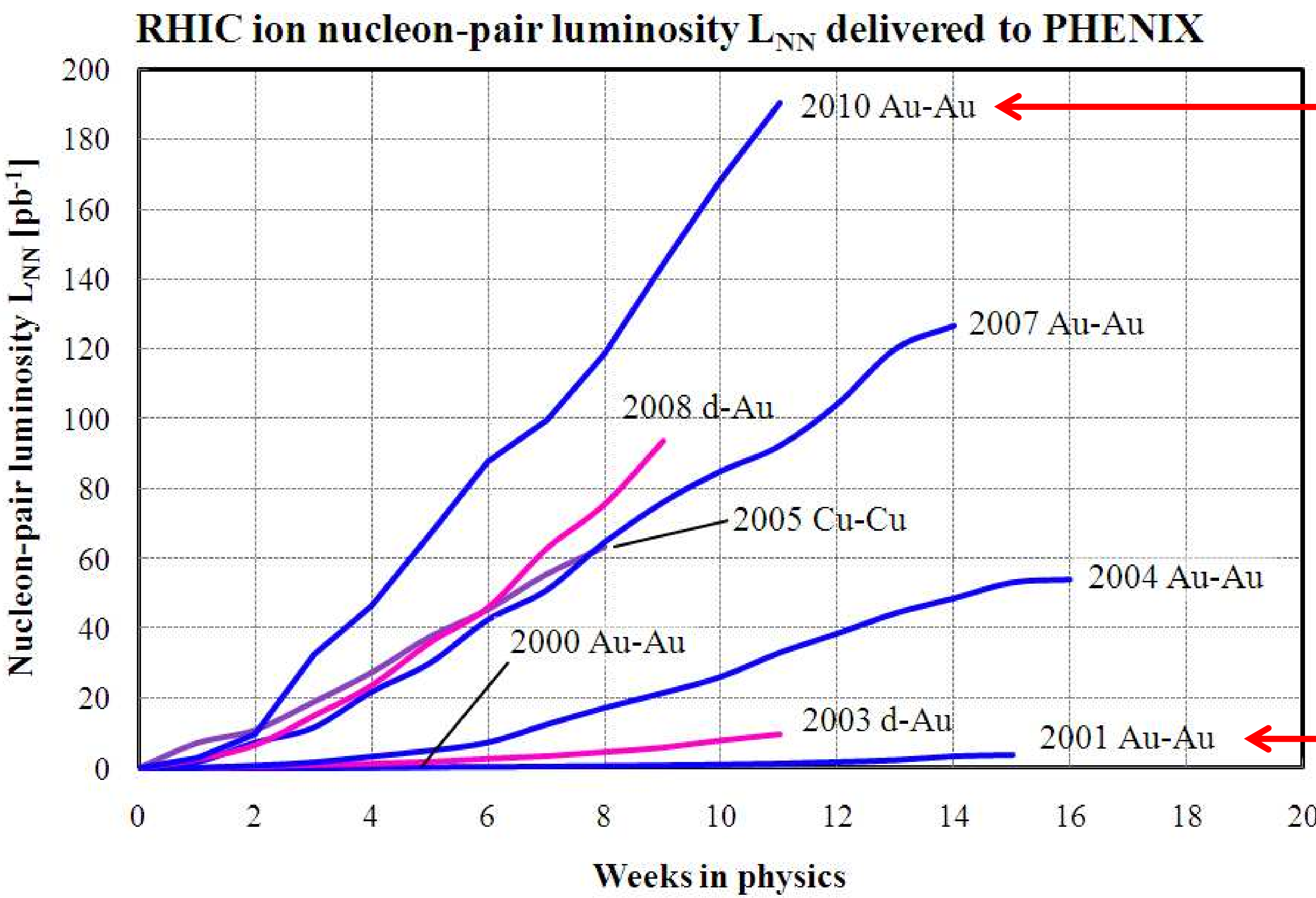


Run 10 Comparison

Run	Year	β^* [m]	no. of bunches	ions/bunch [$\times 10^9$]	L_{peak} [10^{26} cm^{-2}sec^{-1}]	$L_{ave.}$ [10^{26} cm^{-2}sec^{-1}]	L_{week} [μ b^{-1}]	Physics Weeks	$L_{Delivered}$ [n b^{-1}]
design		2	55	1.0	9	2	50		
enhanced design		1	111	1.0	30	8	300		
Run-2	2001	1	55	0.6	4	1.5	24	15.9	0.26
Run-4	2004	1	45	1.1	15	5	160	12	3.53
Run-7	2007	0.83 (PHENIX) 0.77 (STAR)	103	1.1	30	12	380	12.8	7.25
Run-10	2010	0.75	111	1.1	40	20	650	10.9	10.0

RHIC heavy ions – luminosity evolution

$L_{NN} = L\,N_1 N_2$ (= luminosity for beam of nucleons, not ions)



10x design in 2010

reached design in 2001

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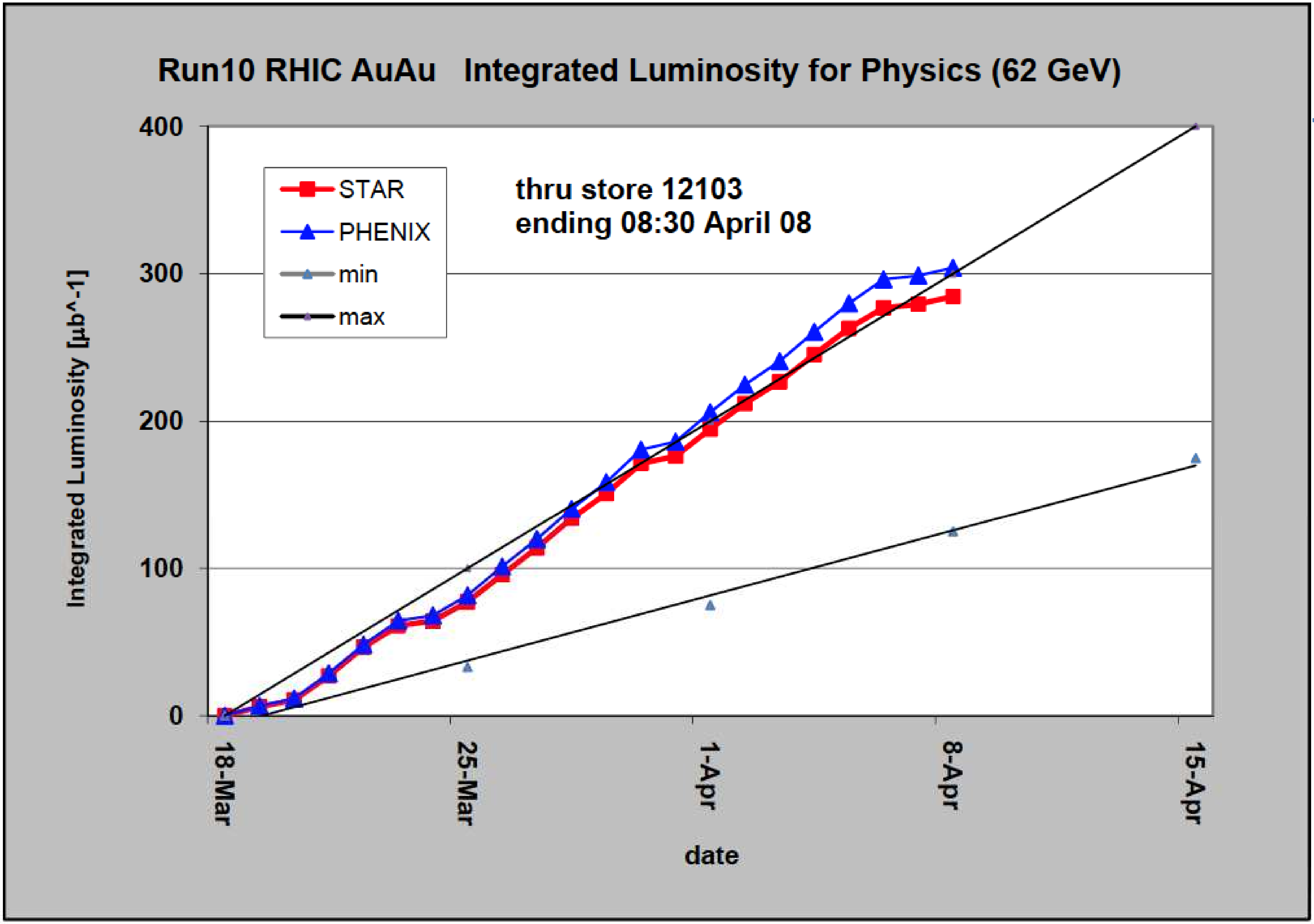
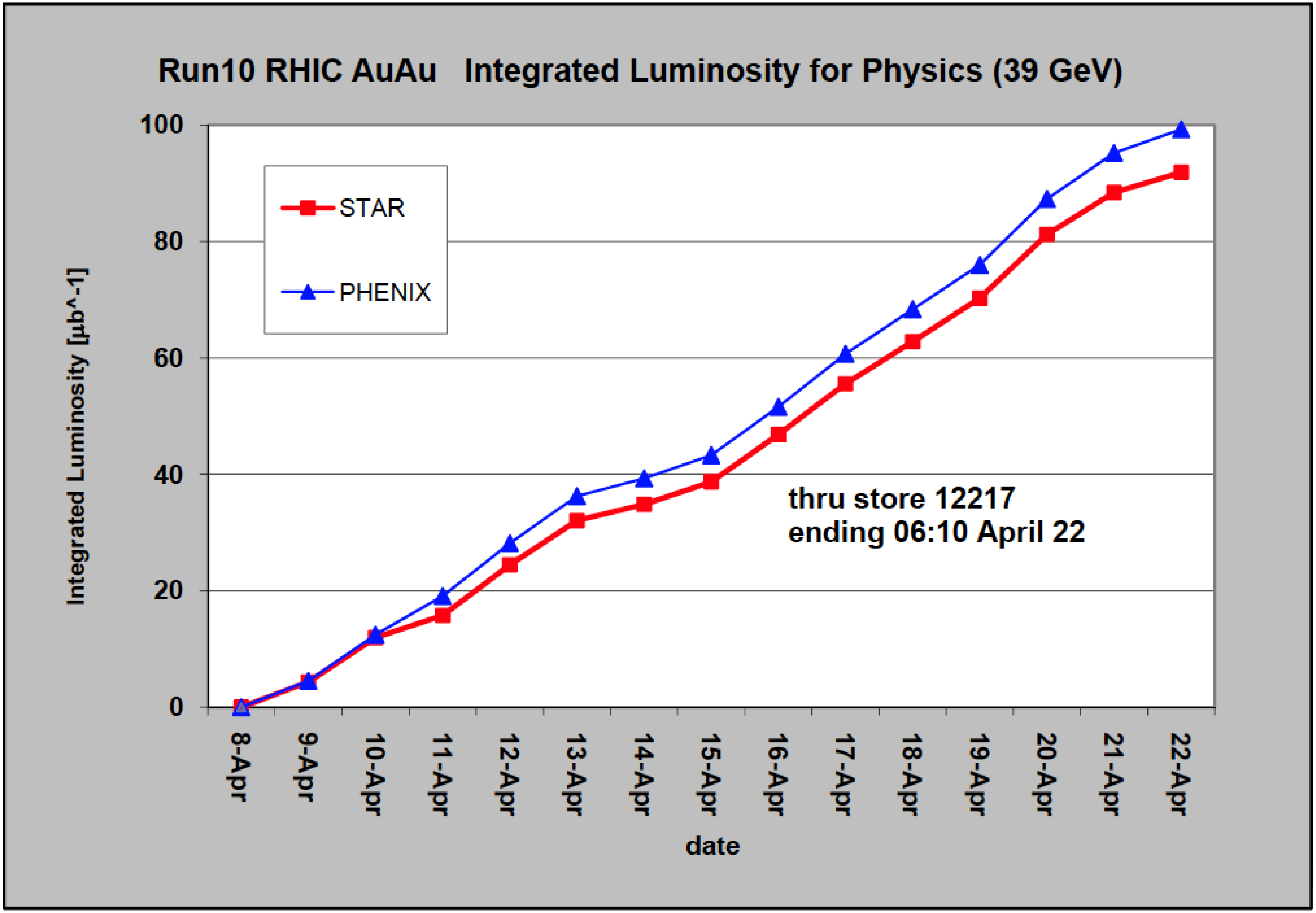
Medium Energy Runs

- 62.4 GeV/n & 39 GeV/n setup periods went very fast.
  - Tune/coupling + orbit feedback for 62.4 GeV/n
  - Added chrom. Feedback for 39 GeV/n
- Integrated Luminosity was better than expected, allowing stretch physics goals to be reached.


Run10 RHIC AuAu Integrated Luminosity for Physics (62 GeV)
thru store 12103
ending 08:30 April 08
STAR
PHENIX
min
max
Integrated Luminosity [μb^-1]
400
300
200
100
0
18-Mar
25-Mar
1-Apr
8-Apr
15-Apr
date


Run10 RHIC AuAu   Integrated Luminosity for Physics (39 GeV)
Integrated Luminosity [μb^-1]
100
80
60
40
20
0
STAR
PHENIX
thru store 12217
ending 06:10 April 22
8-Apr
9-Apr
10-Apr
11-Apr
12-Apr
13-Apr
14-Apr
15-Apr
16-Apr
17-Apr
18-Apr
19-Apr
20-Apr
21-Apr
22-Apr
date

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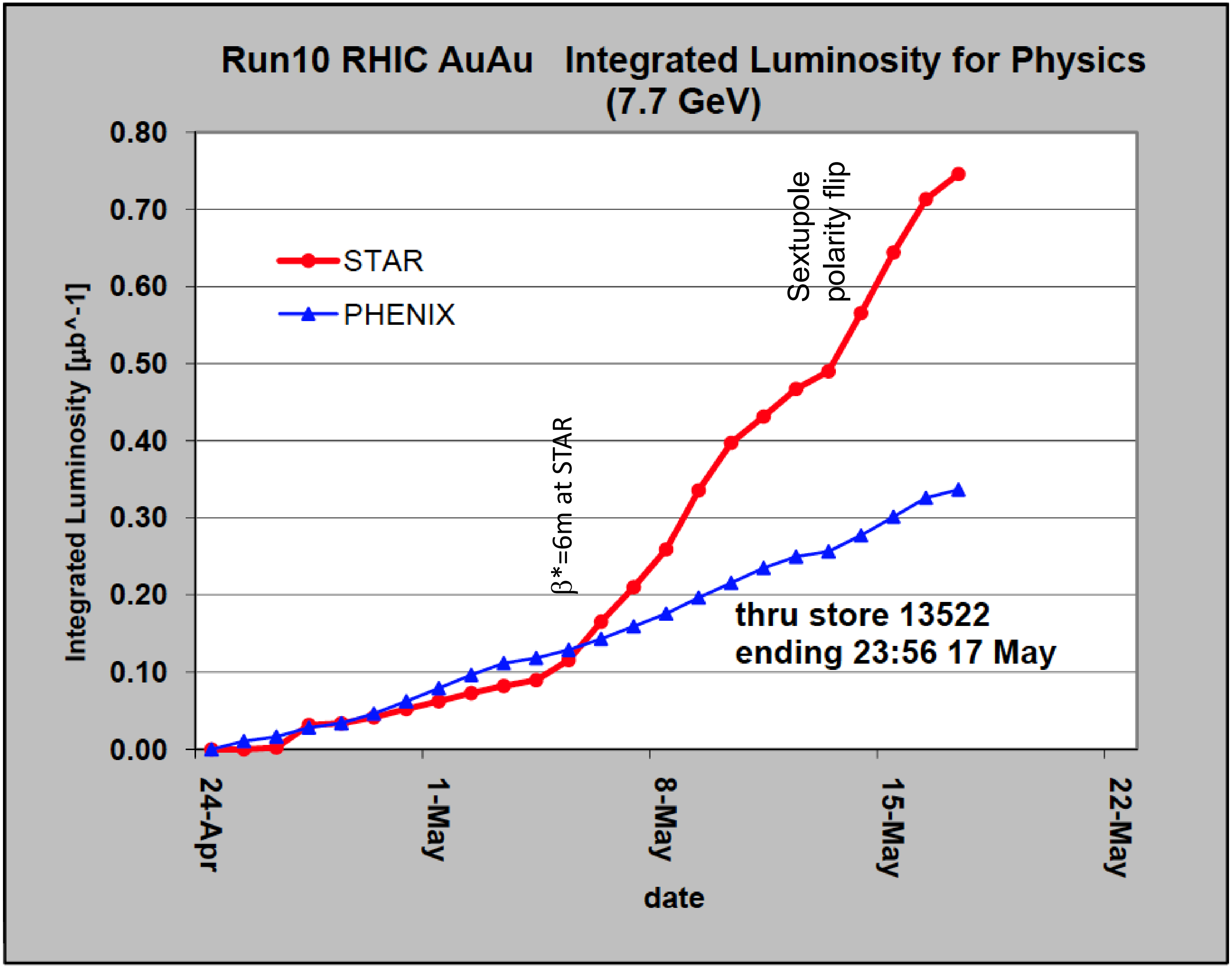
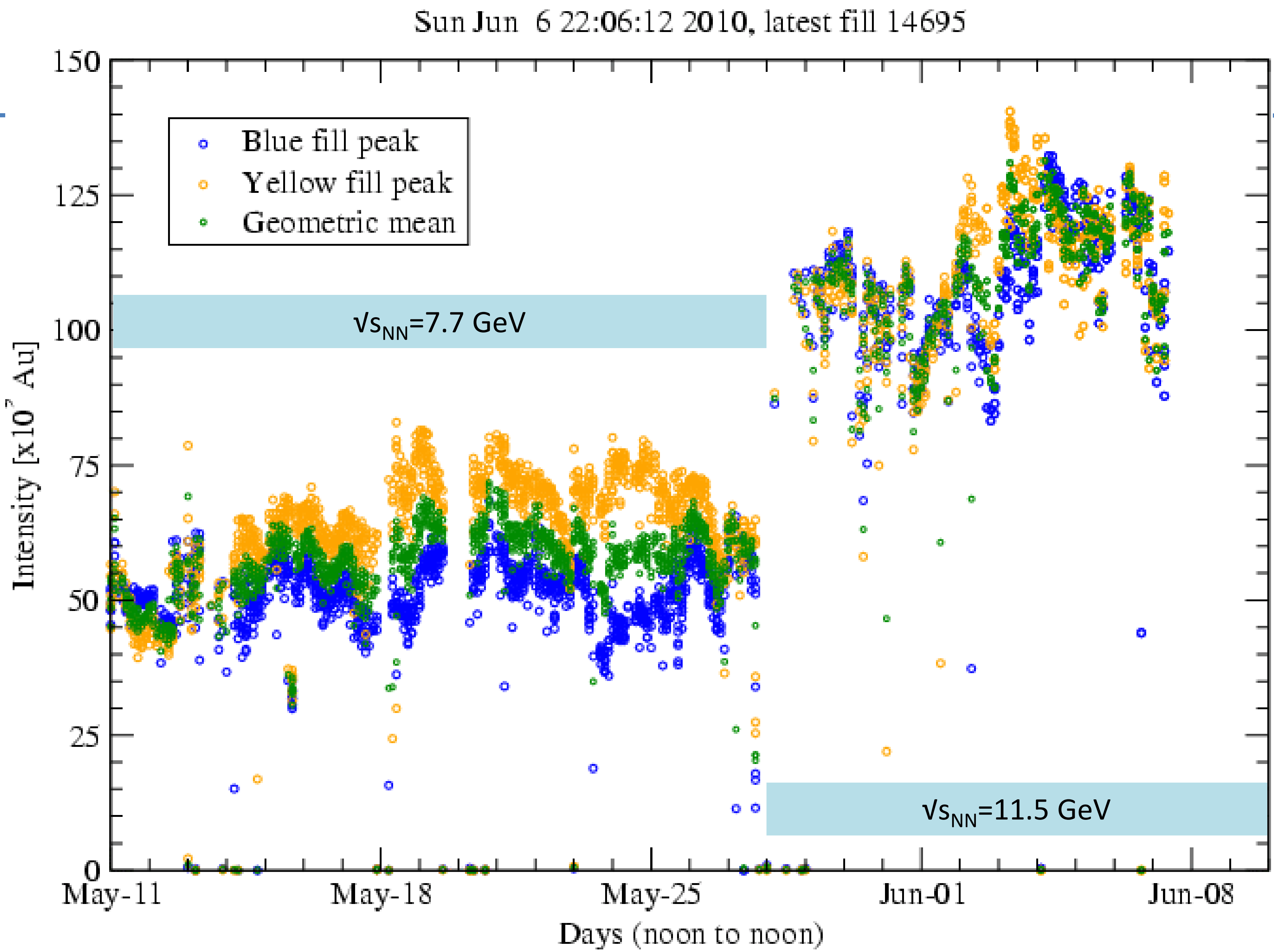
Run-10 Low Energy Issues

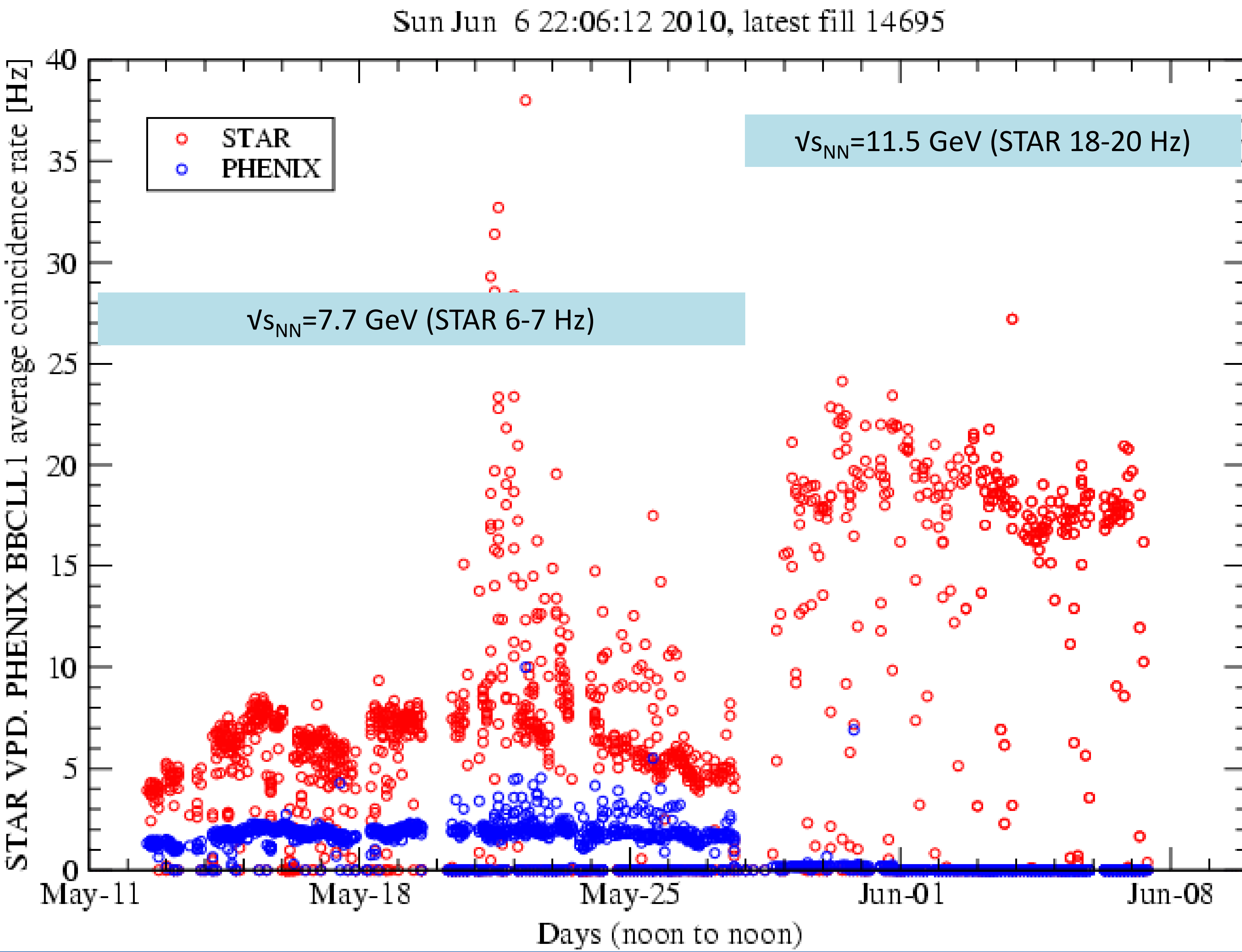
- Collision energies $\sqrt{s_{NN}}$=7.7, 11.5, 5 GeV
  - STAR only at 11.5 GeV; testing only at 5 GeV
  - 35 days to goal (STAR 5M+ events) at 7.7 GeV
- Limiting losses with large low-energy beams
  – Aggressive collimation to reduce backgrounds
  – Loss monitoring/accounting in ATR and RHIC
  – Short stores (10 min), rapid turnaround (2 min)
- Low event rates (1-10 Hz average)
- Limited by beam-beam, space charge



Run10 RHIC AuAu Integrated Luminosity for Physics (7.7 GeV)
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Integrated Luminosity [µb^-1]
STAR
PHENIX
Sextupole polarity flip
β*=6m at STAR
thru store 13522 ending 23:56 17 May
24-Apr
1-May
8-May
15-May
22-May
date



Sun Jun 6 22:06:12 2010, latest fill 14695
Blue fill peak
Yellow fill peak
Geometric mean
√sNN=7.7 GeV
√sNN=11.5 GeV
Intensity [x10^7 Au]
150
125
100
75
50
25
0
May-11
May-18
May-25
Jun-01
Jun-08
Days (noon to noon)



Sun Jun 6 22:06:12 2010, latest fill 14695
STAR
PHENIX
√s_NN=11.5 GeV (STAR 18-20 Hz)
√s_NN=7.7 GeV (STAR 6-7 Hz)
STAR VPD. PHENIX BBCLL1 average coincidence rate [Hz]
0
5
10
15
20
25
30
35
40
May-11
May-18
May-25
Jun-01
Jun-08
Days (noon to noon)

Run-10 Low Energy Observations

- Achieved operational goals of all runs
- Operations was very efficient
  - Very short stores maintained over weeks of ops
- Average luminosity scales close to γ^3
  - Higher than predicted: β^*=6m, higher intensities
- Primary loss concerns are in ATR (^{77}Au stripping)
  - Good RHIC collimation (localized 90+% losses)
- Data collected to understand beam lifetimes
  - Growth consistent with IBS predictions
  - Space charge ~0.1 a new regime for a collider
  - Continue discussions about electron cooling

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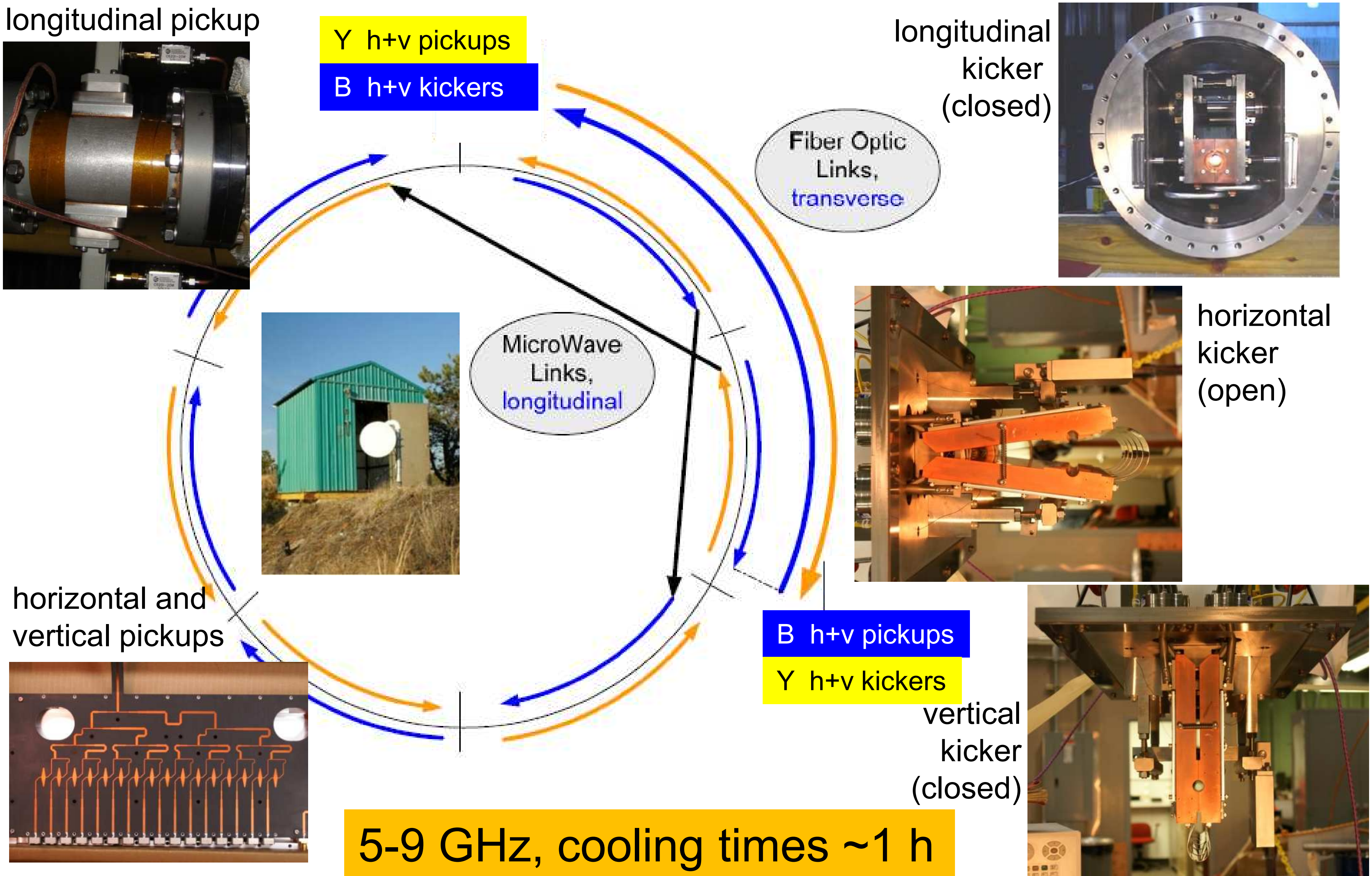
Future Plans for RHIC Ion operations

Heavy ion upgrades

- Stochastic cooling
- 56 MHz SRF
- Electron Beam Ion Source (EBIS)
- RHIC low energy operation and cooling

RHIC – 3D stochastic cooling for heavy ions

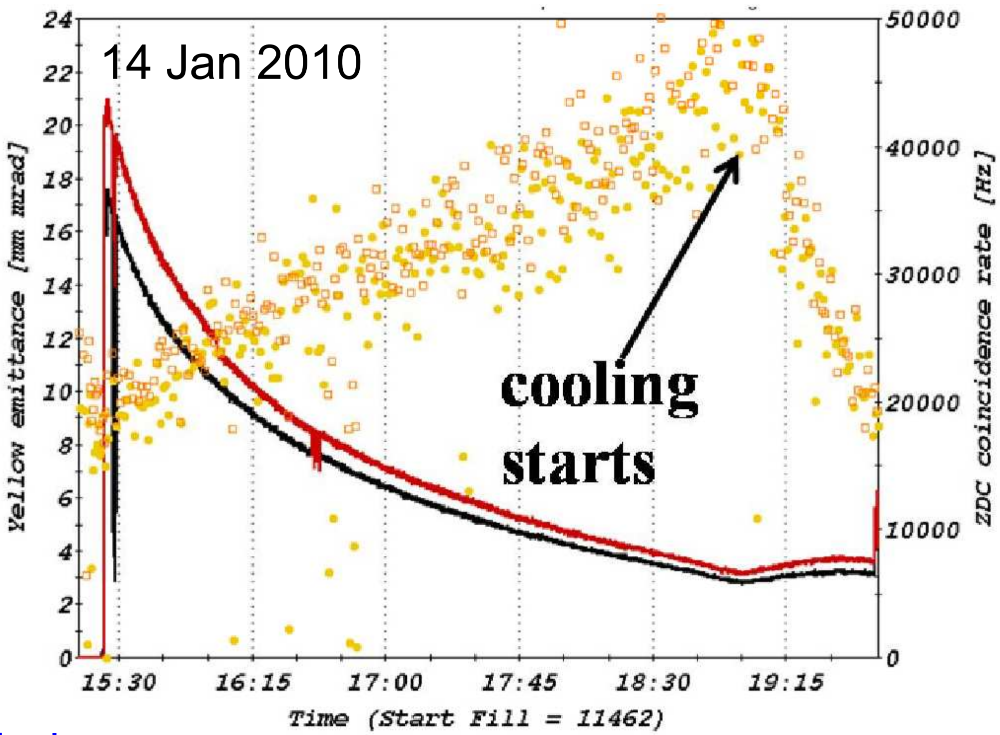


M. Brennan, M. Blaskiewicz, F. Severino, Phys. Rev. Lett. **100** 174803 (2008); PRST-AB, PAC, EPAC

RHIC – bunched beam stochastic cooling for heavy ions

M. Brennan
M. Blaskiewicz et al.

- **Longitudinal cooling since 2007**
- **First transverse (vertical) cooling in 2010**

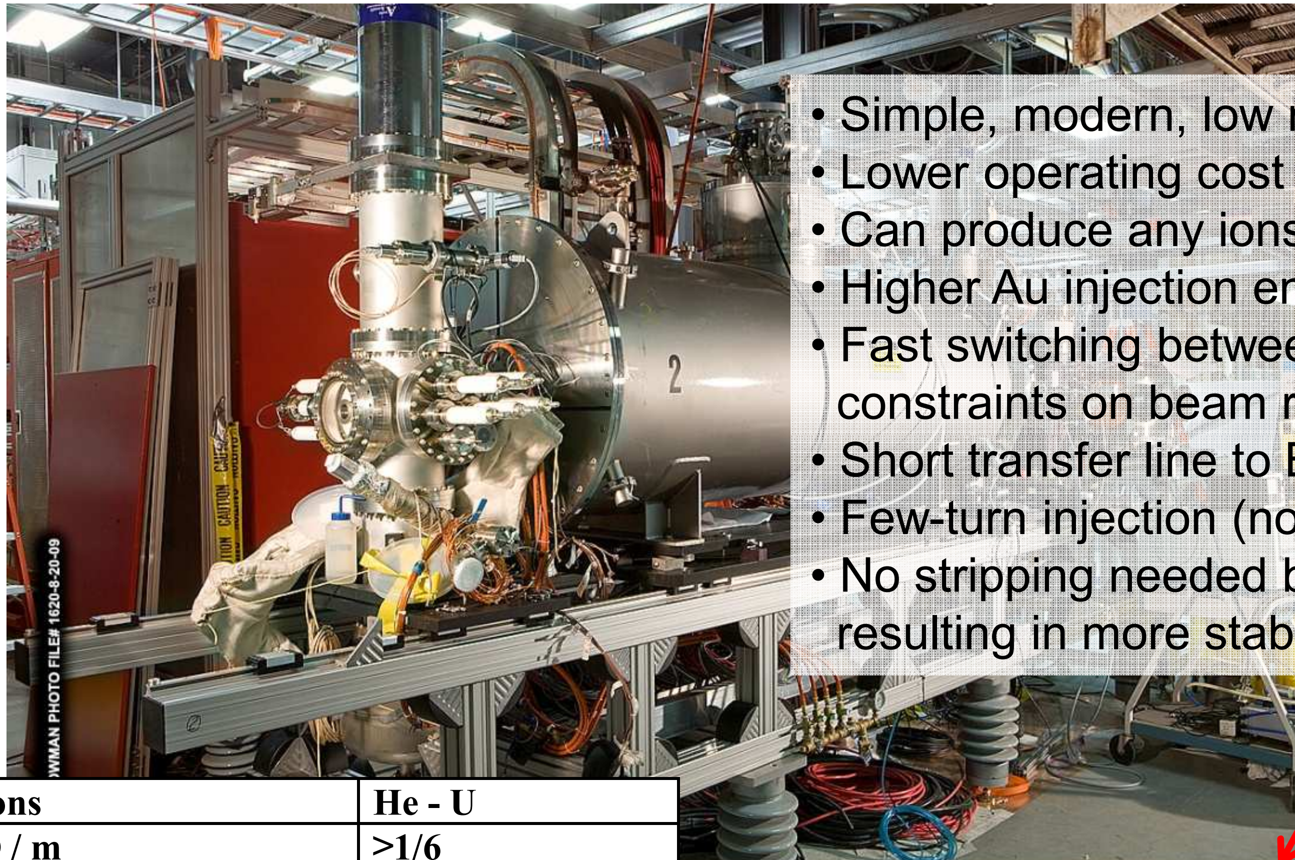


- **So far stochastic cooling increased average store luminosity by factor 2**
- **Expect another factor 2 with full 3D cooling**

Issues:
- Vacuum leaks at feedthroughs
- Mechanical motion of long. kickers
- Cross-talk between Blue and Yellow vertical system (addressed by 100 MHz shift in Blue)
- Construction, installation, and commissioning of horizontal systems

Electron Beam Ion Source (EBIS) (J. Alessi et al.)

10 A electron beam creates desired charge state
in trap within 5 T superconducting solenoid



- Simple, modern, low maintenance
- Lower operating cost
- Can produce any ions (noble gases, U, $He^3\uparrow$)
- Higher Au injection energy into Booster
- Fast switching between species, without constraints on beam rigidity
- Short transfer line to Booster (30 m)
- Few-turn injection (now about 50)
- No stripping needed before the Booster, resulting in more stable beams

Ions	He - U
Q / m	≥1/6
Current	> 1.5 emA
Pulse length	10 μs (1-turn injection)
Repetition rate	5 Hz
Output energy	2 MeV/nucleon
Time to switch species	1 second

RHIC experiments eager to have collision of U nuclei in 2011

(heavier than Au, non-spherical)

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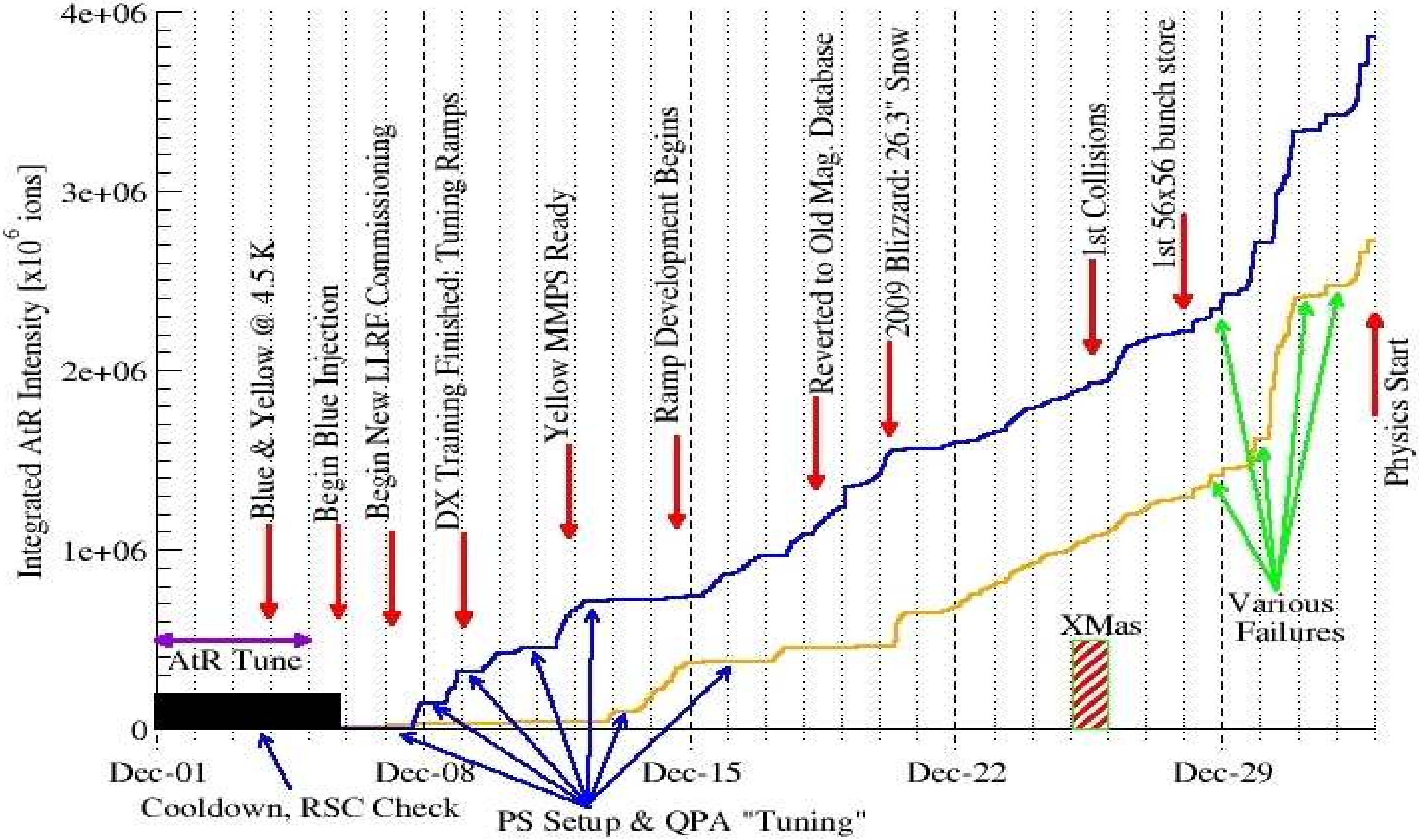
Summary

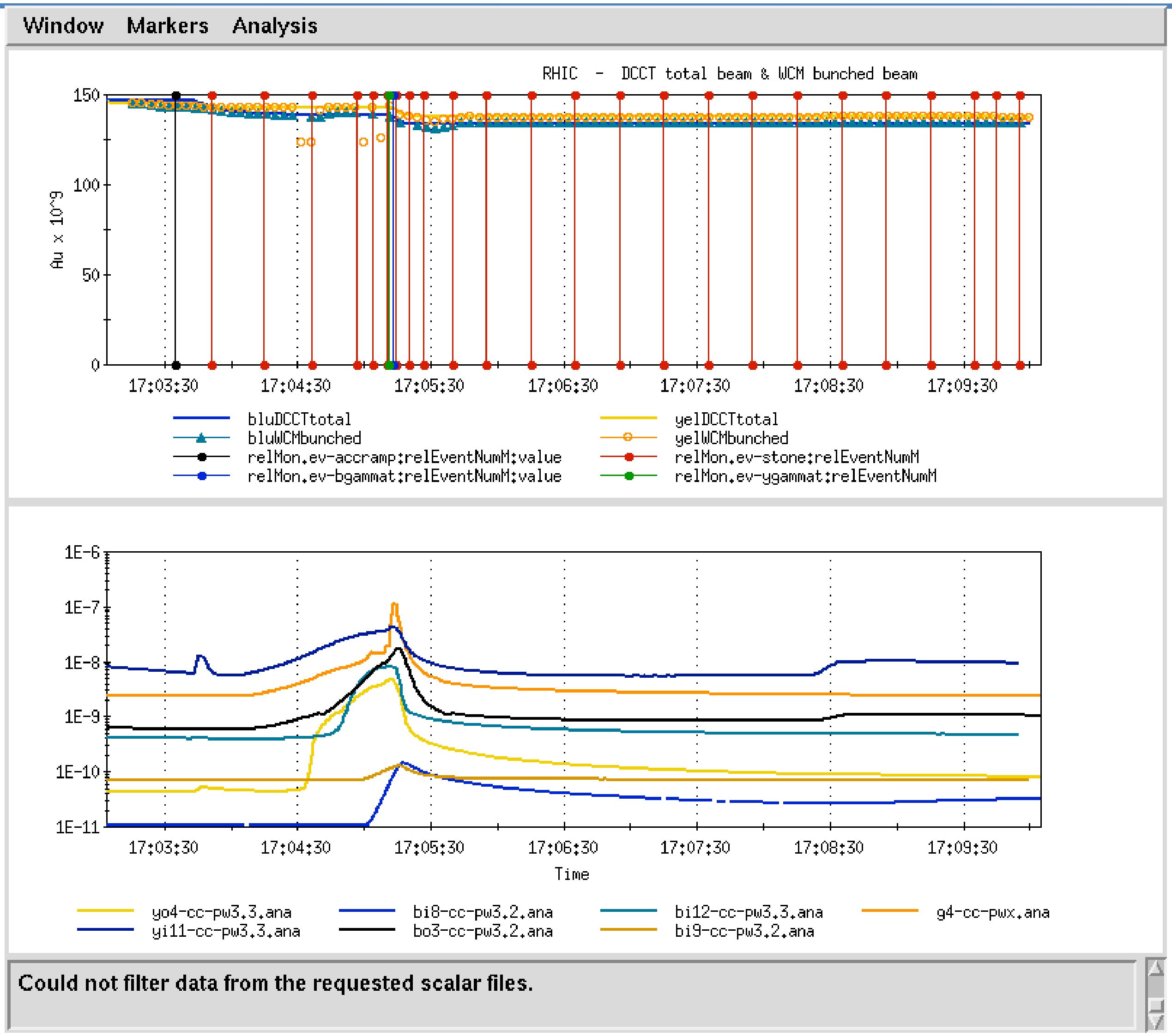
- In Run-10 we ran an aggressive program
- We discovered some of RHIC's limitations
  - Dynamic aperture below $\beta^* = 0.75$m is too small for longitudinal emittances currently achievable
  - No significant instabilities at intensities of 1.5e9/bunch. In Run-7 couldn't go above 1.2e9/bunch
- We commissioned many new systems this year – feedback, LLRF, stochastic cooling
- At 200 GeV/n we integrated almost 2x more luminosity than Run-7 (in the same period of time)
- the low energy runs were a great success and hit all the goals in under the projected time

Backup Slides

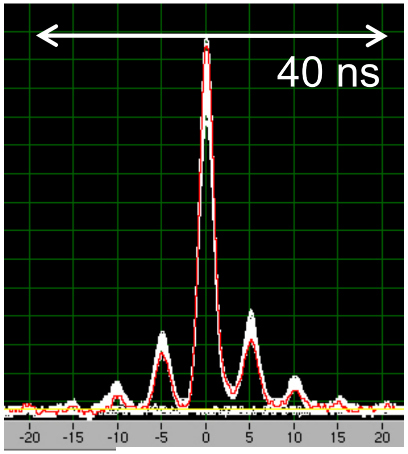
Run-10 Overview: Start-Up



Electron Cloud: Vacuum Pressure Rise

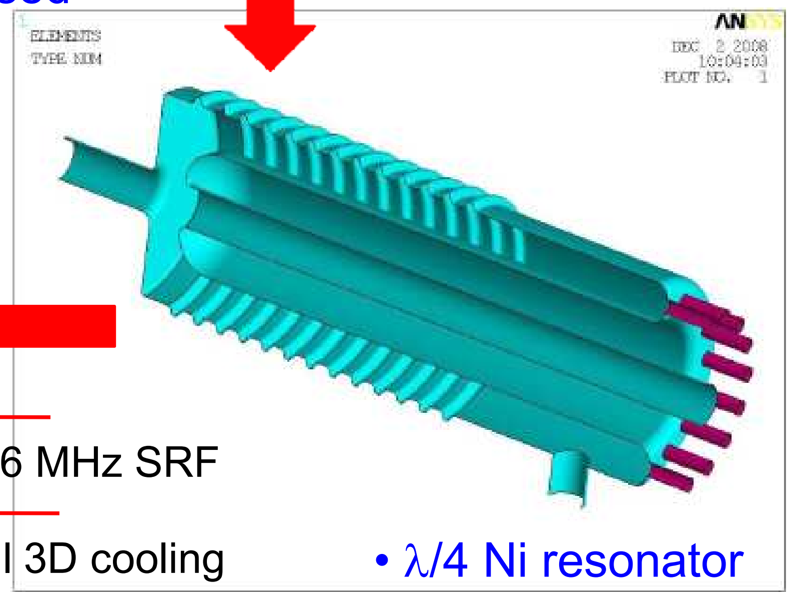


56 MHz SRF for heavy ions – under construction (I. Ben-Zvi et al.)

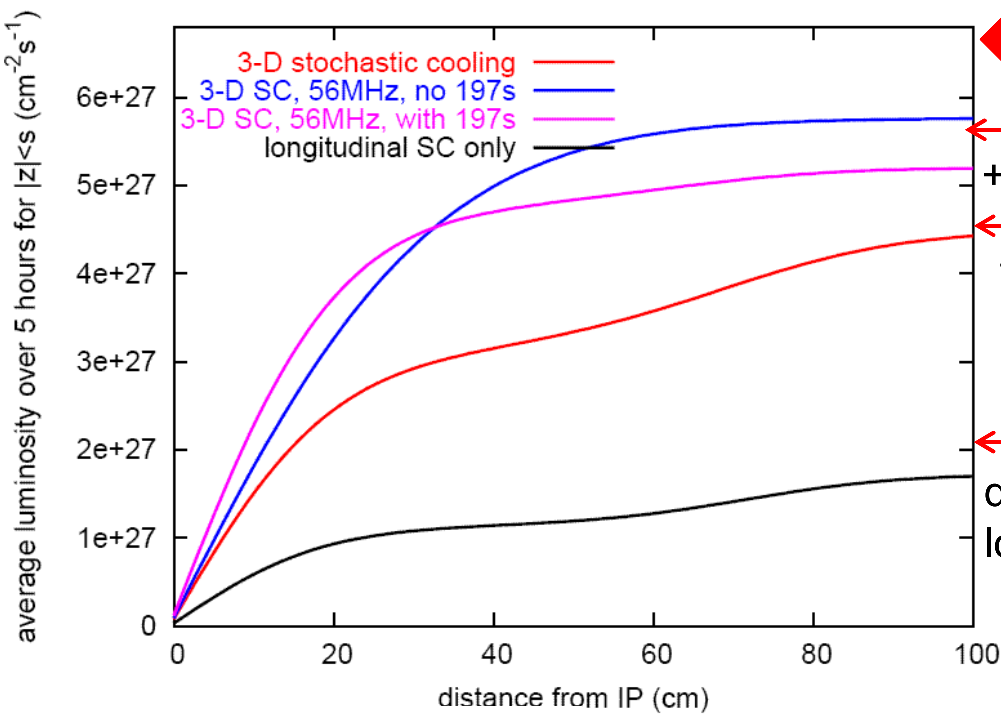


Longitudinal profile at end of store

- even with cooling ions migrate into neighboring buckets
- can be reduced with increased focusing



Average luminosity vs. vertex size



+ 56 MHz SRF

full 3D cooling

demonstrated 2010
long. + ver. cooling

- $\lambda/4$ Ni resonator
- common to both beams
- beam driven
- 56 MHz, 2 MV

Calculations by M. Blaskiewicz

e-cooling for low energy collider operation (A. Fedotov et al.)

Considering use of Fermilab Pelletron (used for pbar cooling at 8 GeV) **after Tevatron operation ends**

Cooling into space charge limit
ΔQ_{sc} ~ 0.05 **(new collider regime)**

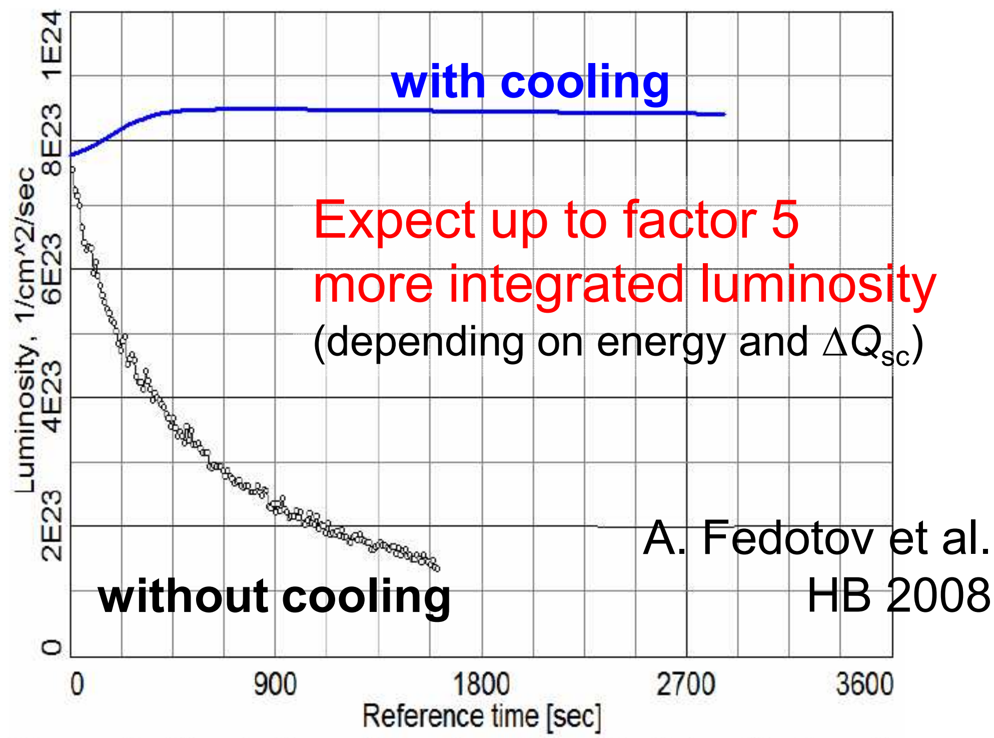
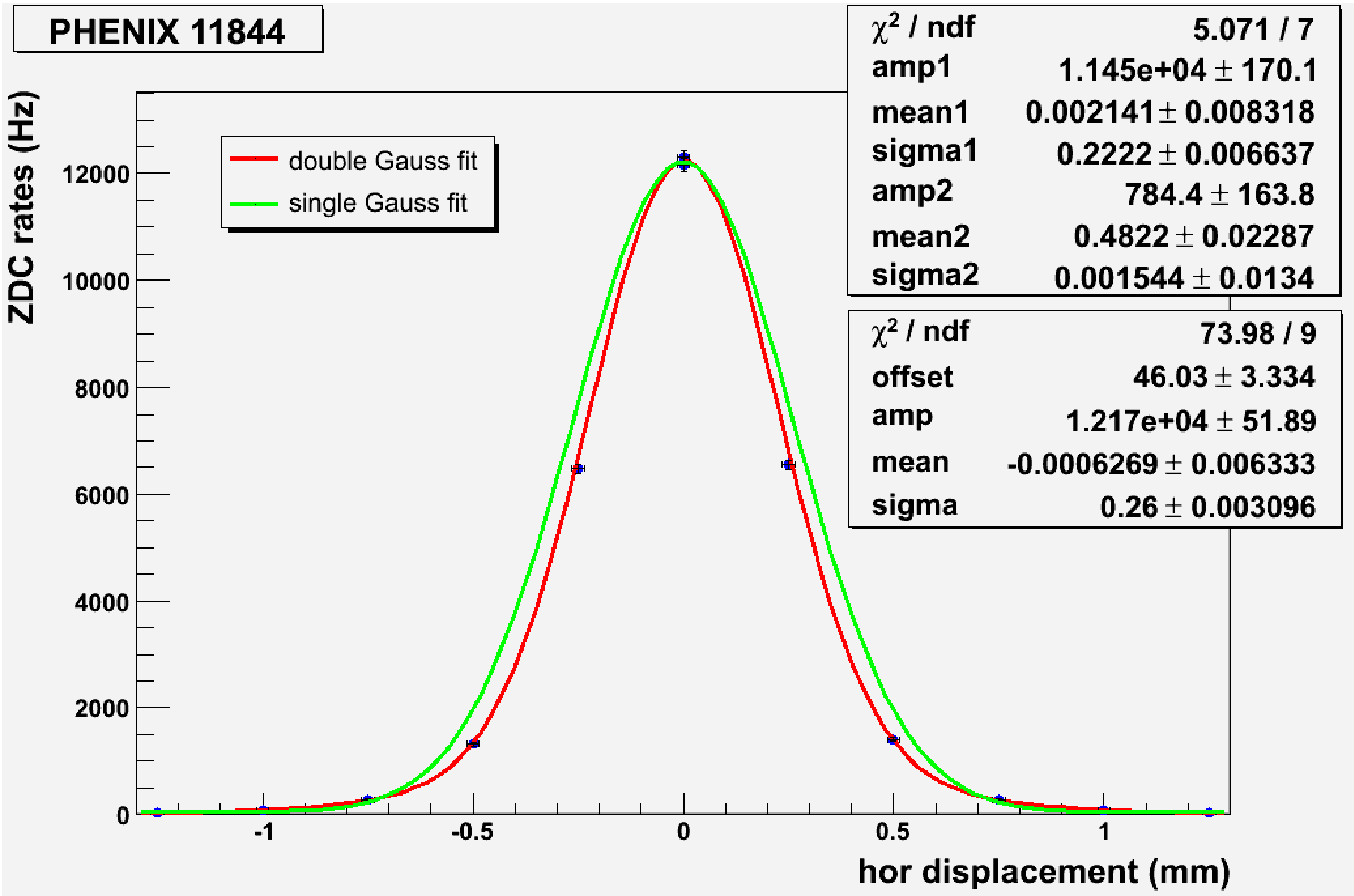


Figure 4. Simulation of luminosity with (blue line) and without (black dots) electron cooling at γ=2.7.

Vernier Scans



Vernier Scans